Status of EUVL Multilayer Optics Deposition at RIT

Yuriy Platonov, Jim Rodriguez, Mike Kriese, Vladimir Martynov

Rigaku Innovative Technologies, 1900 Taylor Rd., Auburn Hills, MI 48326, USA

Outline

- RIT introduction
- ML deposition facility
- Metrology
- EUVL projects
- New capabilities
- Conclusion

Rigaku

Rigaku Innovative Technologies, Inc.

Osmic® X-ray Products

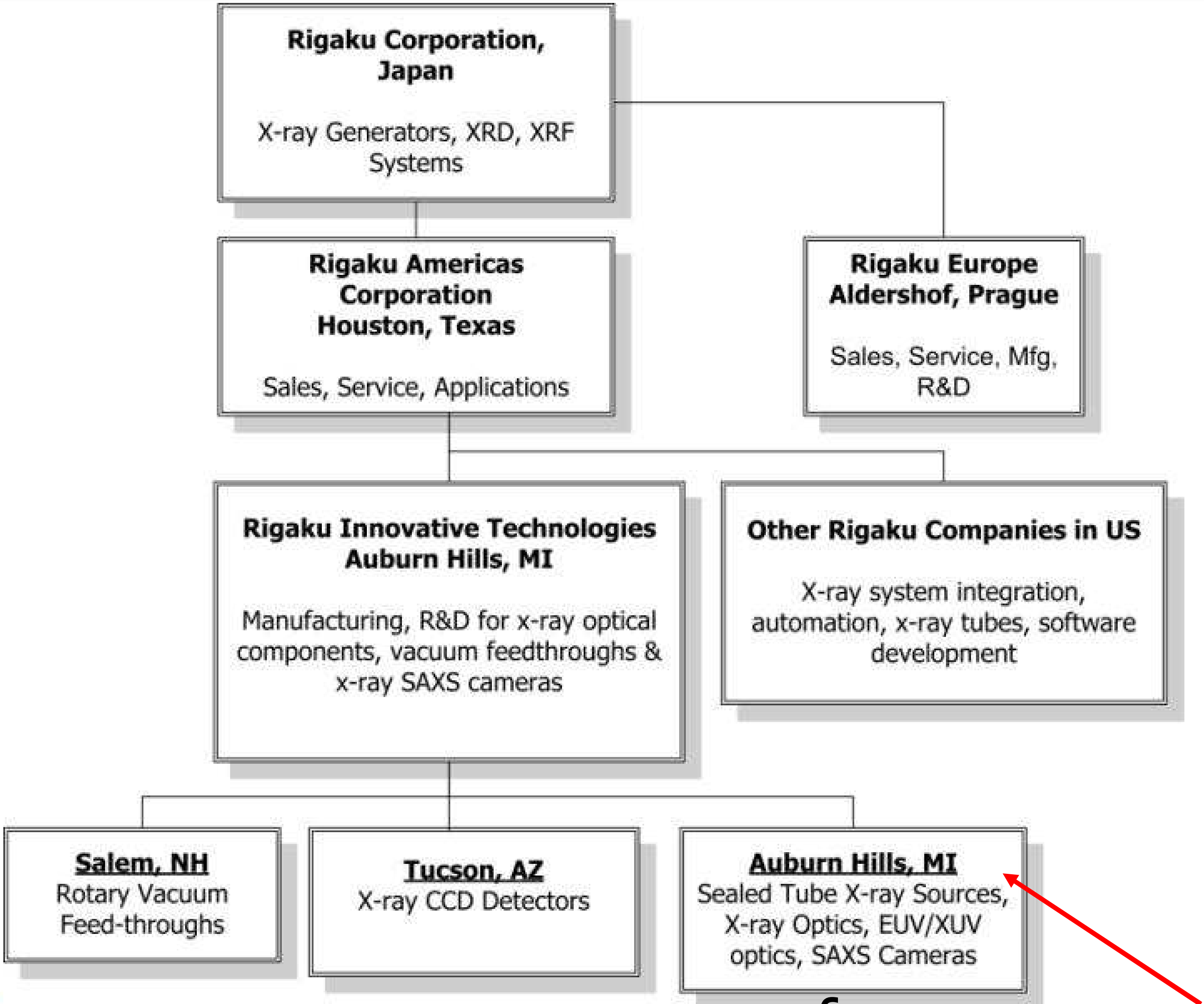
RIT is part of Rigaku Global Organization

X-ray Measurement Systems and Components

Manufacturing, R&D, Sales, Service

$300M annual revenue

www.rigaku.com

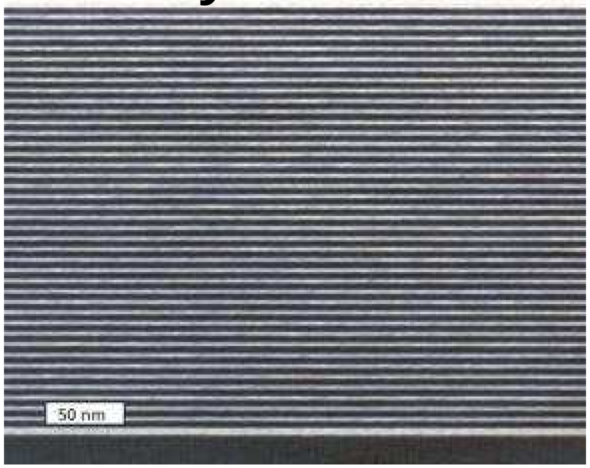


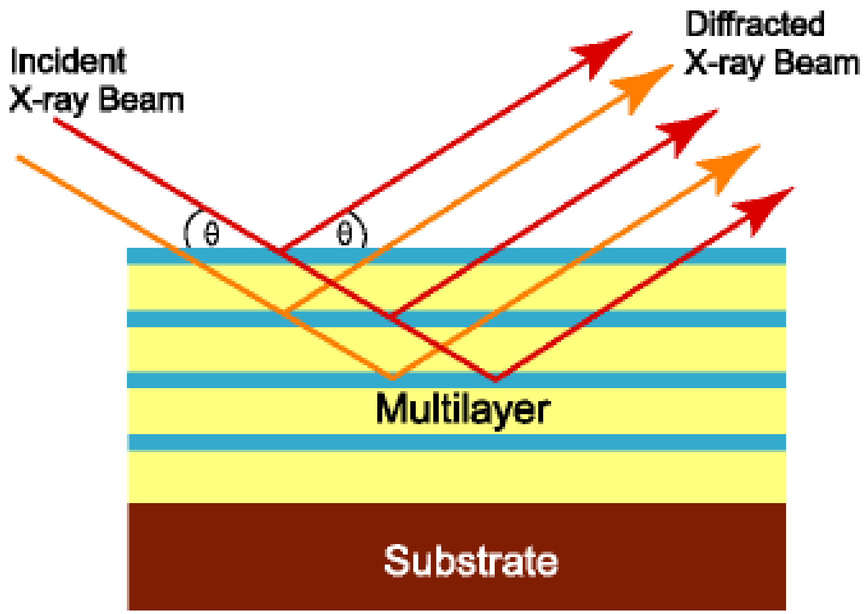
Rigaku

former Osmic Inc.

RIT Product–optics for hard and soft x-rays

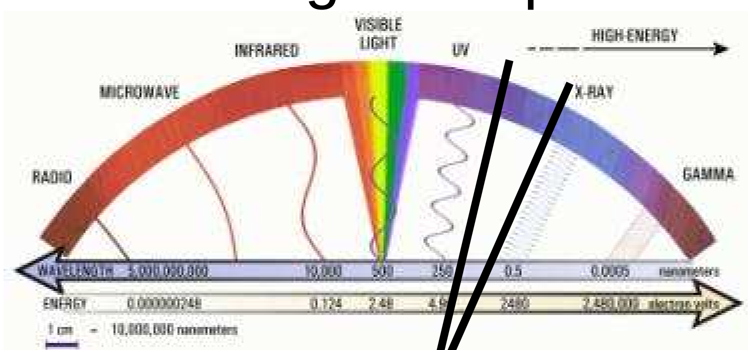
multilayer thin films

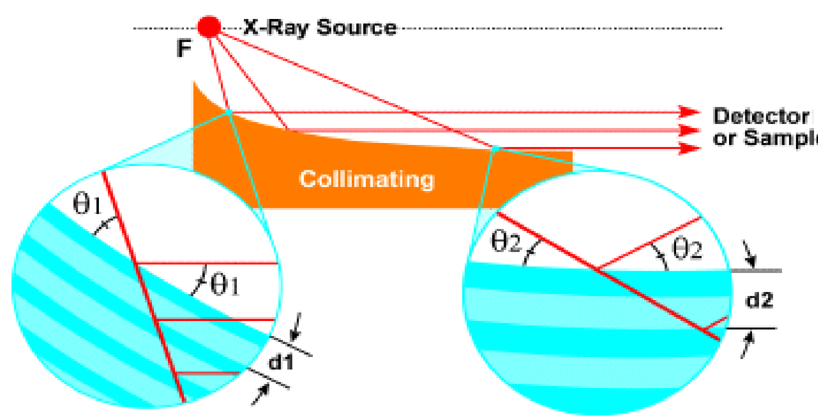




Collimating Multilayer Optic

electromagnetic spectrum





XUV ~ 2 nm-20 nm range (approx.)
EUV = 13.6 nm exactly

Rigaku

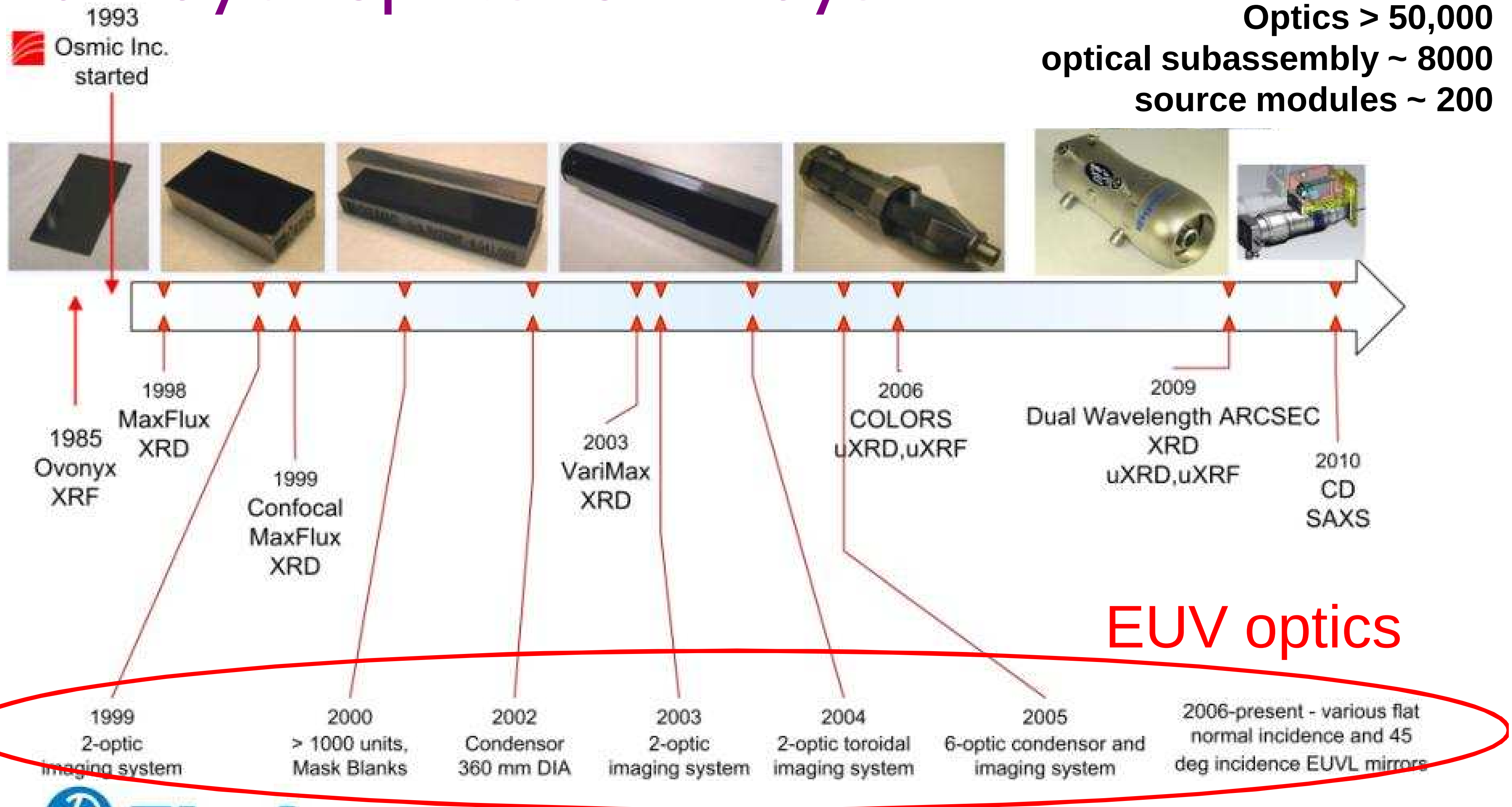
RIT/Osmic pioneered and commercialized multilayer optics for x-rays

Units Shipped:

Optics > 50,000

optical subassembly ~ 8000

source modules ~ 200



Multilayers deposition facility

Innovative Technologies

- **Inline Magnetron**
- **7 Carousel Magnetrons**
- **Ion Beam**
- **Class100 cleanroom with class 10 miniroom**

25 years of ML production

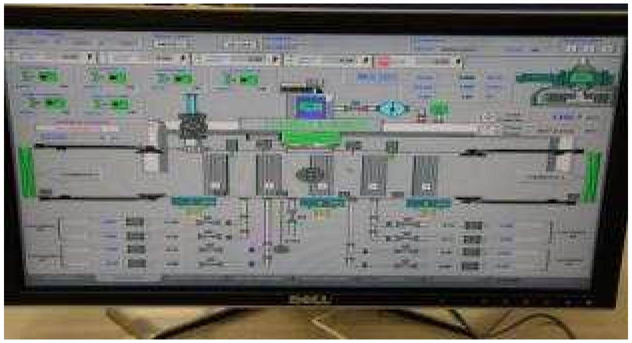
- **Wavelength Range**
  λ = 0.2Å – 300Å
  E = 40eV – 60keV
- **Multilayer Period**
  d_{min} = 10Å
- **Number of Period**
  N_{max} = 1000
- **Spectral Resolution**
  $\Delta\lambda/\lambda$ = 0.2% (high-selective)
  20% (depth-graded)
- **Size**:
  ~3mm to 1.5 meter

- **Materials**
  W/Si, W/C, Ni/Ti, Ni/B_4C, Ni/C, Cr/C, Cr/Sc, Mo/Si, Mo/B_4C, La/B, V/C, Ru/B_4C, Al_2O_3/B_4C, SiC/Si, Si/C, SiC/C, Fe/Si, Cr/B_4C, Si/B_4C, W/Mg_2Si, V/B_4C, Ti/B_4C, etc.
- **Design**
  Uniform or Graded: lateral, radial, bilateral (2D)
  Depth Graded: supermirror & high-selective
  Flat or Curved
  Glancing (<1º) to Normal

Rigaku

Inline Magnetron

Innovative Technologies



- Vacuum (load-locked)
  - 10^{-8} ultimate
  - 10^{-9} water
  - 15min from atm to 10^{-6}
- Process
  - 5 planar magnetron (RF,DC)
  - 4 process gases
  - 0.5 to 5 mTorr
  - linear ion source
  - 20-100 particles/cm^2 on optical surface
- Dual Spinning Capability

  #1: 450mm dia x 100mm thick

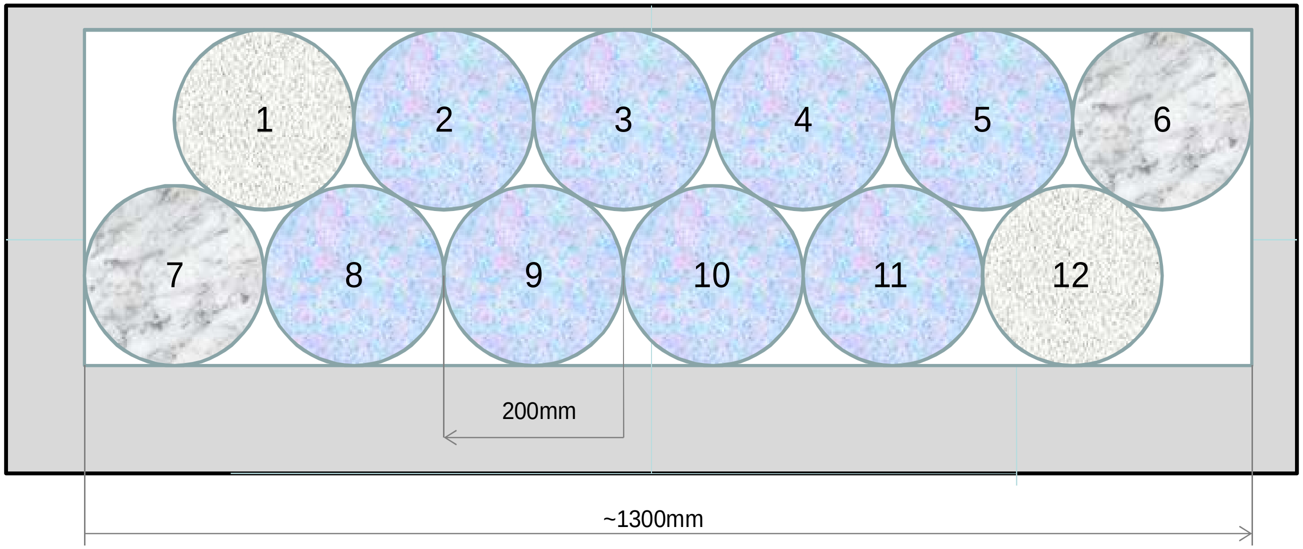
  #2: 175mm dia x 35mm thick

  (Compatible with velocity motion control)
- Mechanical
  - 500 x 1500mm carrier (2)
  - 0.2mm accuracy
  - 1-133 mm/sec (±0.1%)
  - velocity profiling (6 pts/mm)

Rigaku

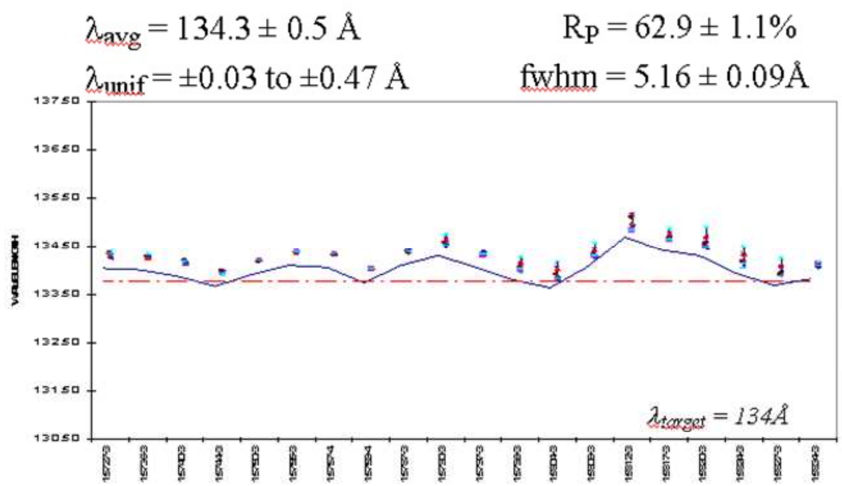
Deposition of 8" mask blanks (1999)

Innovative Technologies



Maximum 12 8" wafers were loaded per deposition run

- Coated over 1000 mask blanks (1999-2000)
- Typical run was 30 blanks/day
- Typical λ_c 13.5 ± 0.02nm within 6" wafer
- Typical R_p = 63 ± 1% within 6" wafer
  (Si cap layer of ~11nm)
- Particulates brought down from 55,000/cm^2 to ~50/cm^2 over project
  (record value ~13/cm^2)

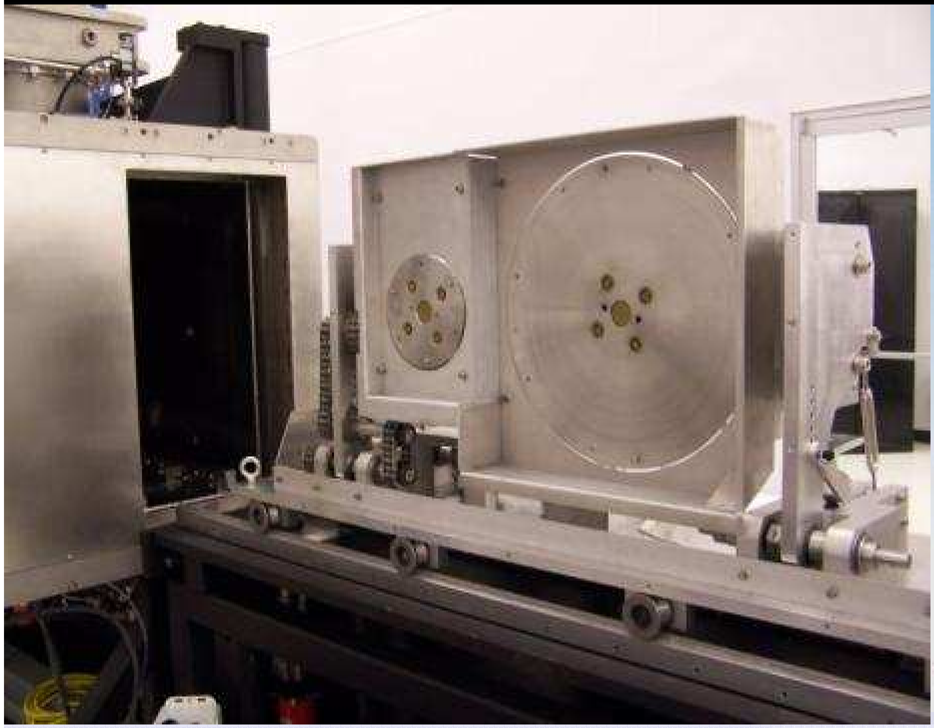


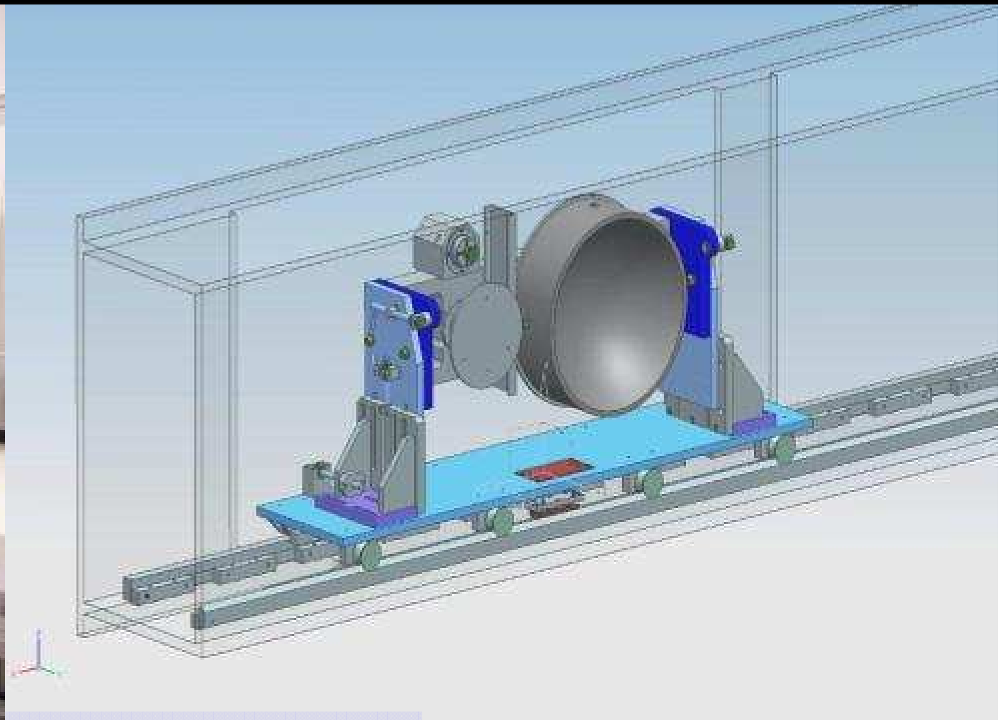
20 runs, 9 measurements/blank

Rigaku

Rotary cart upgrade. InLine.

Innovative Technologies





New Cart

Maximum size:

Diameter – 550mm

Thickness – 220mm

Schedule:

Parts delivery
- Dec. 10, 2010

Assembling
- Dec. 23, 2010

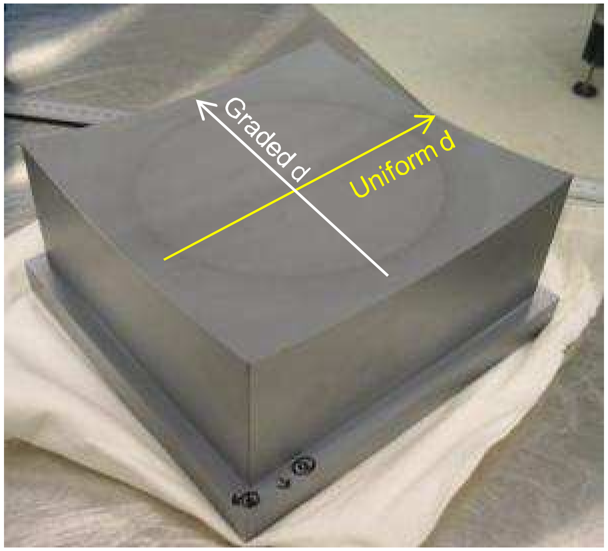
Testing
- Jan. 31, 2011

Commissioning
- Feb. 1, 2011

Rigaku

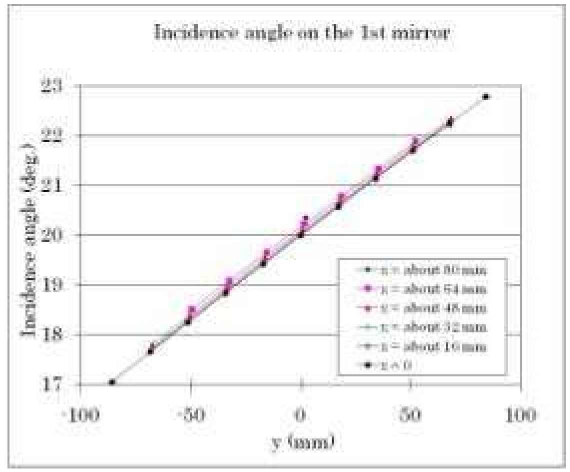
EUVL 2-Optic Imaging System (2004)

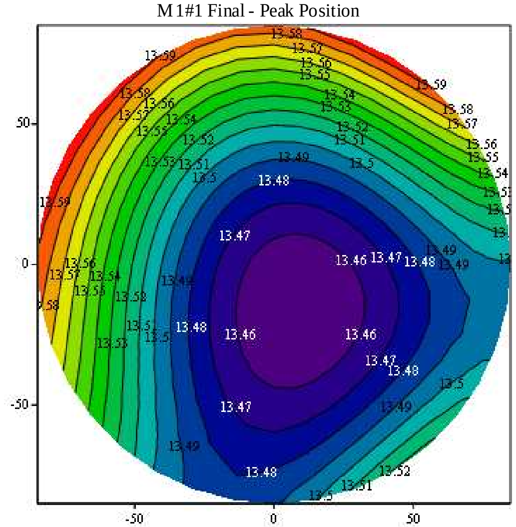
Innovative Technologies



Mirror #1

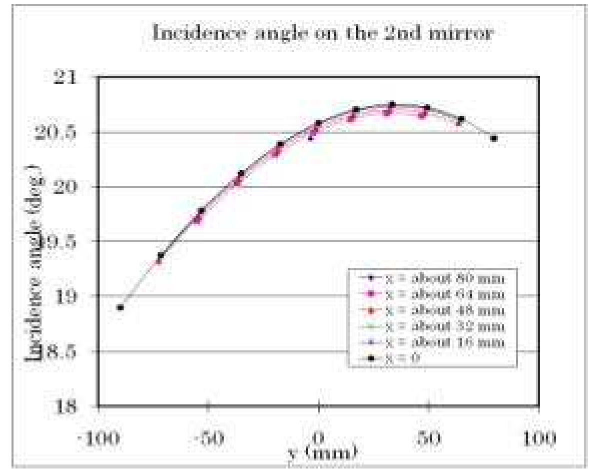
Range of Data: 13.40-13.54 nm
Average Reflectivity: 61.6%

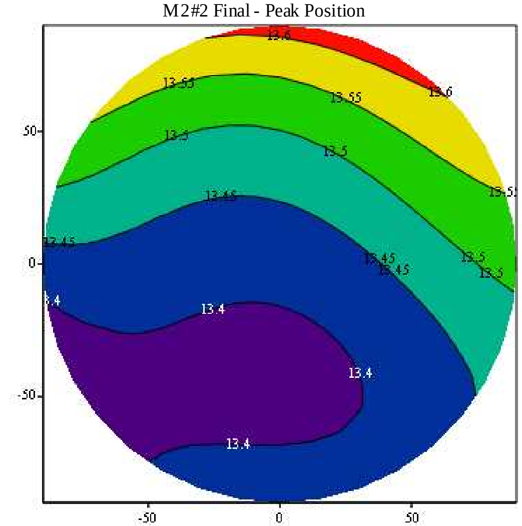




Mirror #2

Range of Data: 13.36-13.59 nm
Average Reflectivity: 61.4%





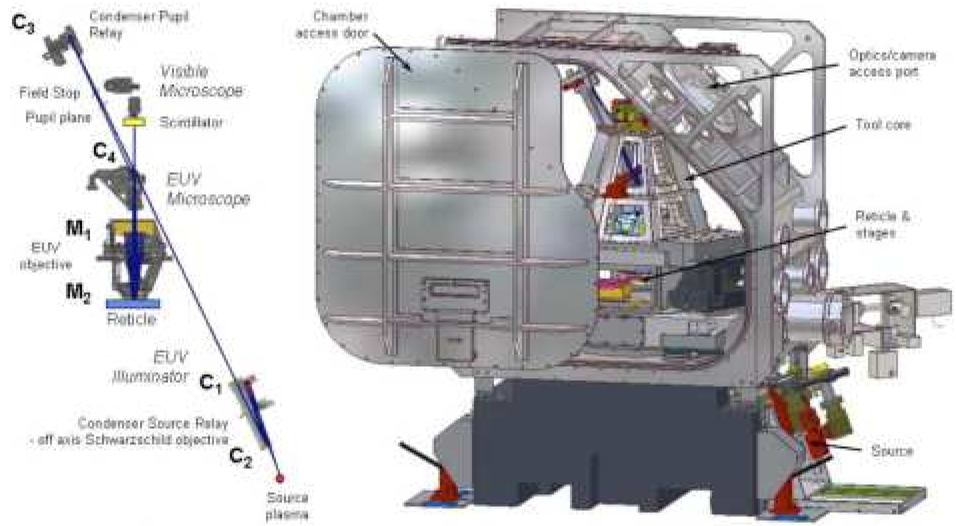
- 200mm toroidal R~350-600
- 2D non-radial gradient
- Ru/B_4C topcoat *(best R_p 67.1%)*
- Achieve < ±1% wavelength on all four optics *(2 sets of 2)*

Rigaku

6-Optic Condensor/Imaging (2005)

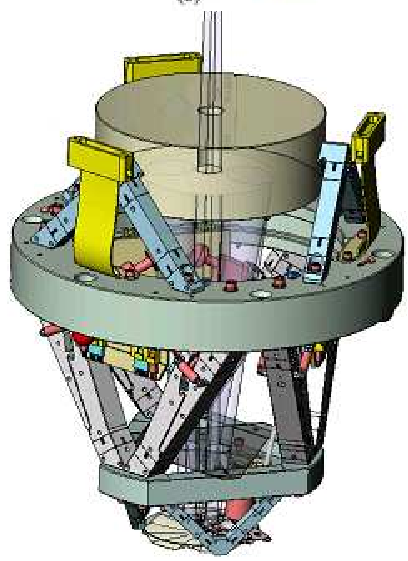
Innovative Technologies

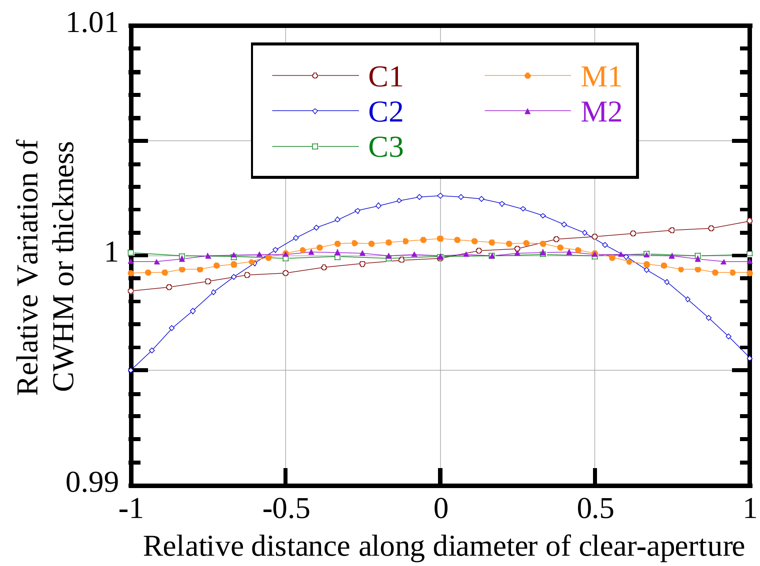
Reticle Imaging Microscope:Tinsley/Exitech RIM



(a) (b)

- 4 condensor (1 Ru, 3MoSi)
- 2 imaging (MoSi)
- Added Figure Error in imaging optics:
  - M1: 0.015nm (± 0.018nm λ_c in CA)
  - M2: <0.010nm (± 0.005nm λ_c in CA)



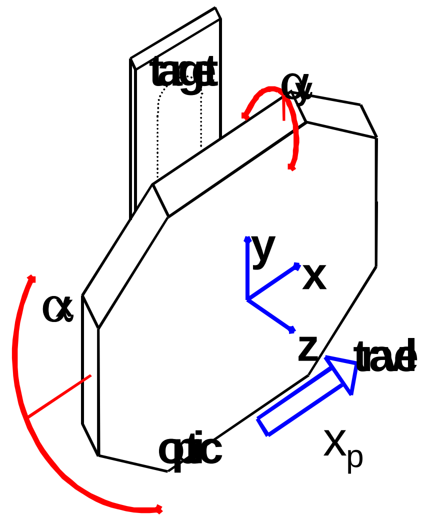


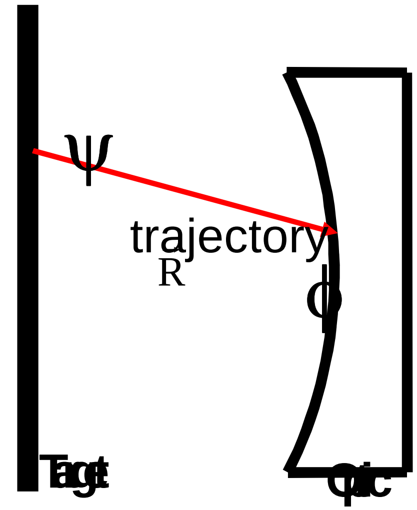
H.Glatzel et al. Characterization of prototype optical surfaces and coatings for the EUV Reticle Imaging Microscope, Proc. of SPIE, Vol. 5751 (2005), 1162 – 1169.

Rigaku

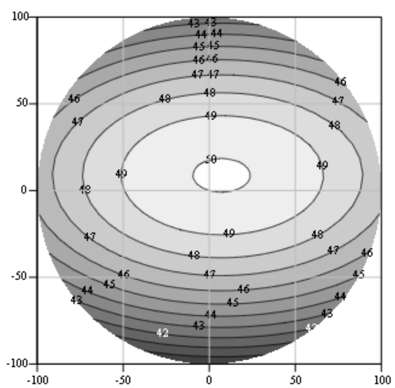
Deposition Simulations

- Practical simulation of the deposition, using distributed array of point sources
- Accommodate geometry of system & substrate
- Predict coating results, capability, sensitivity; reduce calibration time
- Successfully used for flat optics, cylindrical, spherical and aspherical optics (radial & 2D)

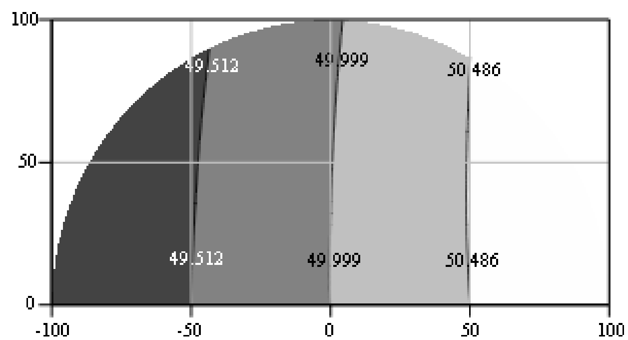




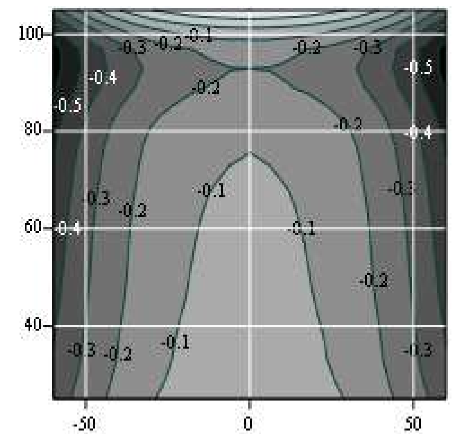
Non-radial on sphere



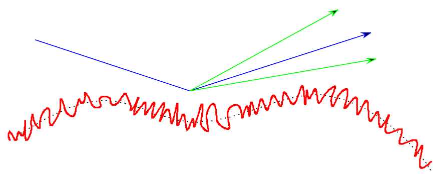
Linear on sphere



Uniform on cylinder



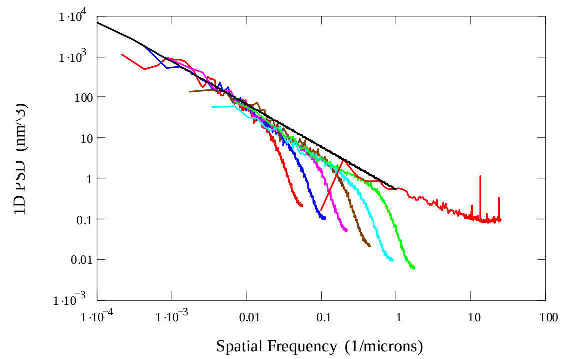
In-House surface characterization

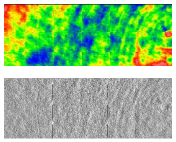


$$PSD(f) = \frac{2 \cdot \delta}{N} \cdot \sum_{n=1}^{N} e^{2 \cdot \pi \cdot \imath \cdot (n-1) \cdot \delta \cdot f} \cdot z(n)$$

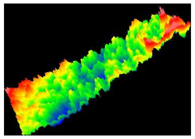
PSD is surface roughness power per unit spatial frequency.

$$\sigma_{RMS} = \sqrt{\int_{f1}^{f2} PSD(f) \cdot d(f)}$$





rms 2.2 sec, 2 nm

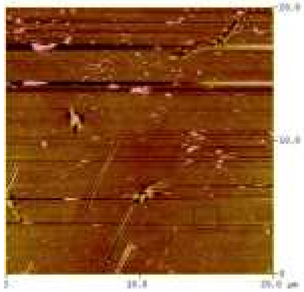


25 x 10 mm, Filter 50µm – 5 mm

- **Mid Spatial Frequency Roughness (MSFR)**

  Spatial periods ~1µm – 5mm

  Instrument -**Interferometric Microscope** manufactured by **Zygo**, model New View 6300. Installed in class 100 clean room



- **High Spatial Frequency roughness (HSFR)**

  Spatial periods ~10nm - 5µm

  Instrument -**AFM** manufactured by Veeco, model #DI3100. Installed in class 100 clean room

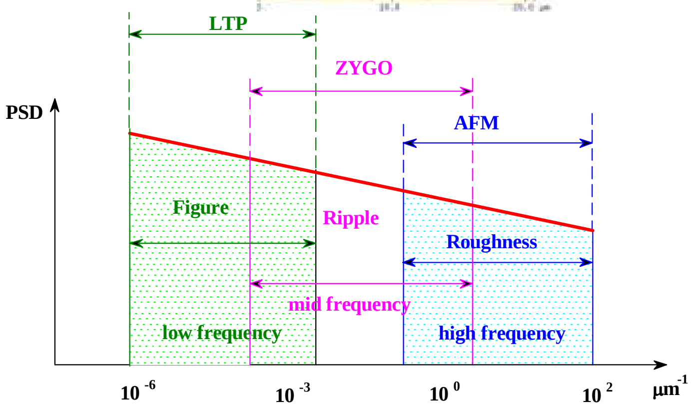
Low @ Mid Spatial Roughness

Instrument – Contact Profilometer **Talysurf**

Spatial periods >10µm

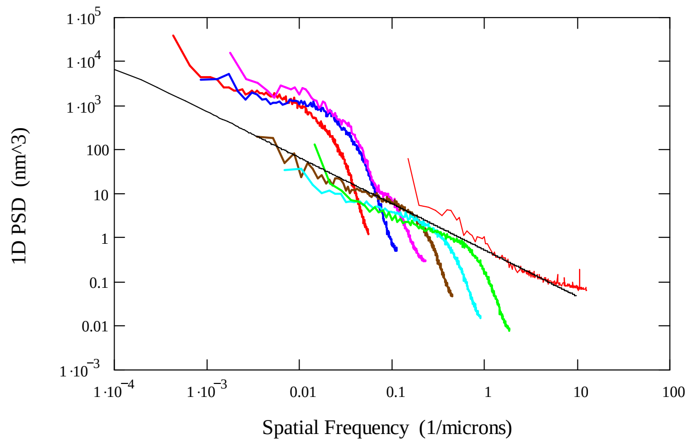
Max scan range -200mm, accuracy - 0.5µm

Rigaku



Mo/Si multilayers surface roughness

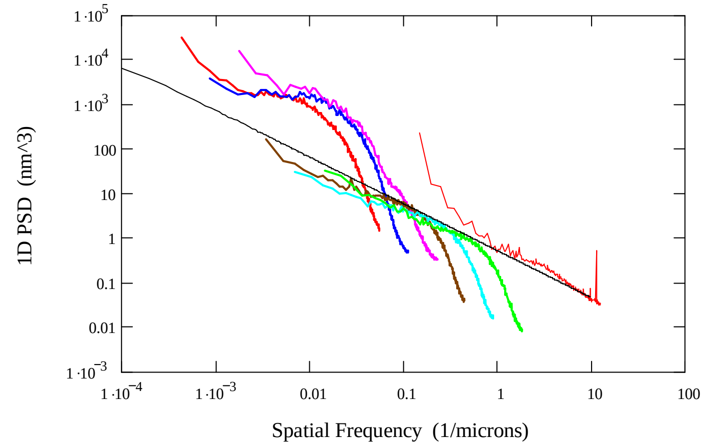
0.5" dia. Si substrate before coating



- Zygo 1.25x
- Zygo 2.5x
- Zygo 5x
- Zygo 10x
- Zygo 20x
- Zygo 40x
- AFM 20x20 microns
- Go_Round_Si

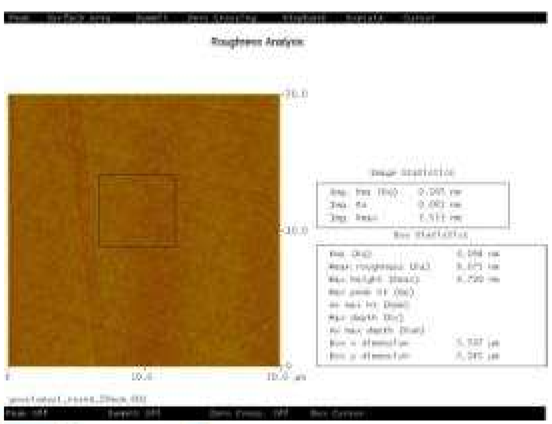
σ = 2.2A for 1.25x
σ = 2.6A for 2.5x
σ = 2.8A for 5x
σ = 1.2A for 10x
σ = 0.5A for 20x
σ = 0.7A for 40x
σ = 1.0A for AFM 20x20 microns

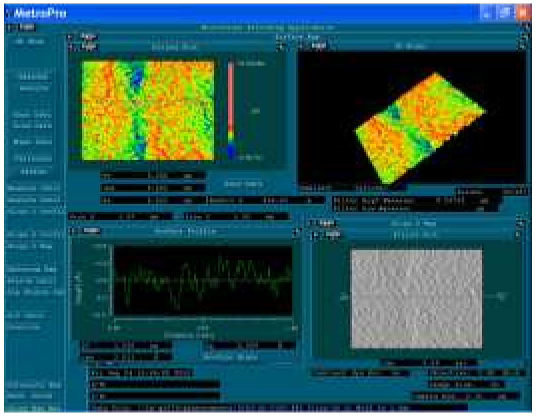
Same after depositing 40 bi-layers of Mo/Si with d≈7nm



- Zygo 1.25x
- Zygo 2.5x
- Zygo 5x
- Zygo 10x
- Zygo 20x
- Zygo 40x
- AFM 20x20 microns
- Go_Round_Si

σ = 2.3A for 1.25x
σ = 2.1A for 2.5x
σ = 2.8A for 5x
σ = 1.7A for 10x
σ = 0.5A for 20x
σ = 0.8A for 40x
σ = 1.0A for AFM 20x20 microns



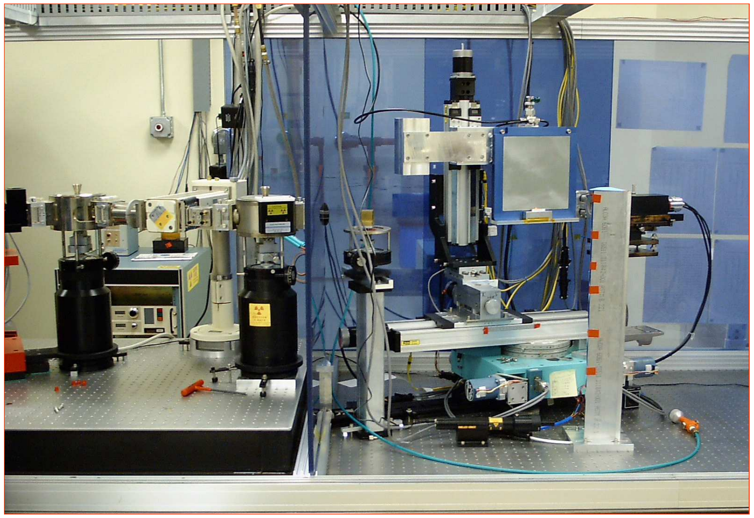


AFM and Zygo interferometer images after depositing Mo/Si multilayer structure

In-House XUV Characterization

Innovative Technologies

Cu-K$_{\alpha}$ diffractometers (λ=1.54Å)
3 instruments for ML reflectivity testing

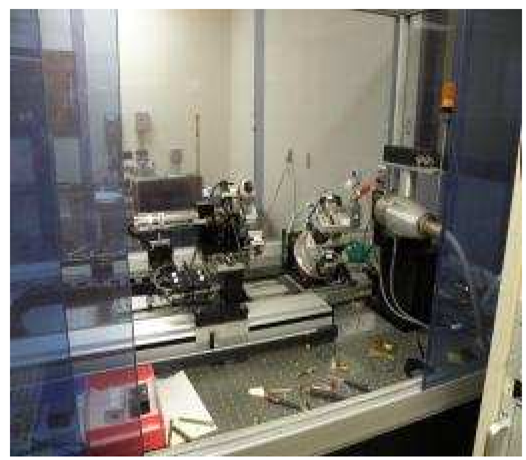


UV reflectometer (λ=150nm – 350nm)
Maximum samples size – 300mm

XRF spectrometer (λ > ~5Å)

Rigaku

MF/CMF tester

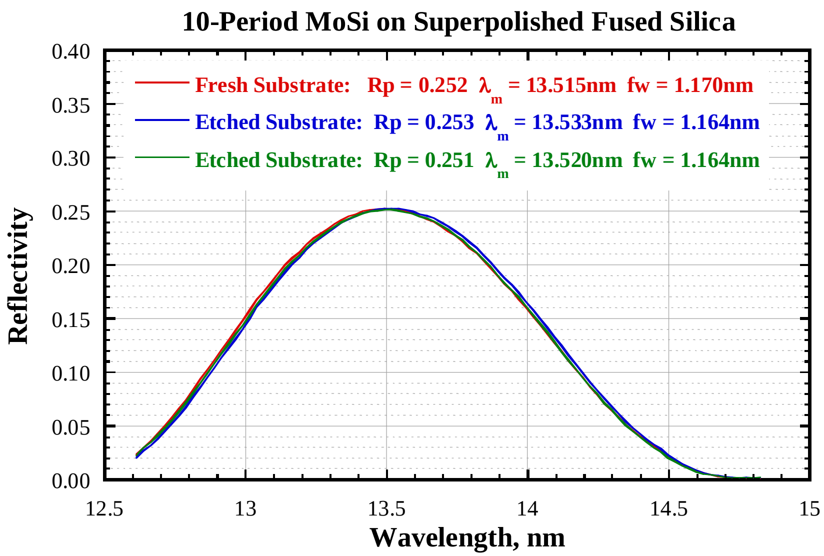


Microsource characterization

Substrates recovery

Innovative Technologies

Wet Chemical Stripping

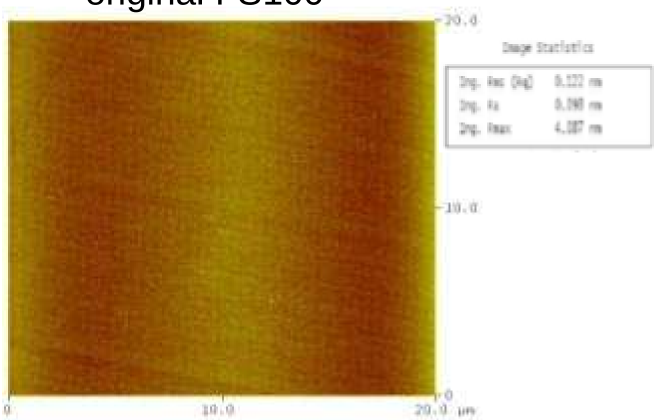


Convex optics were stripped, recoated, re-stripped and re-recoated (N=10):

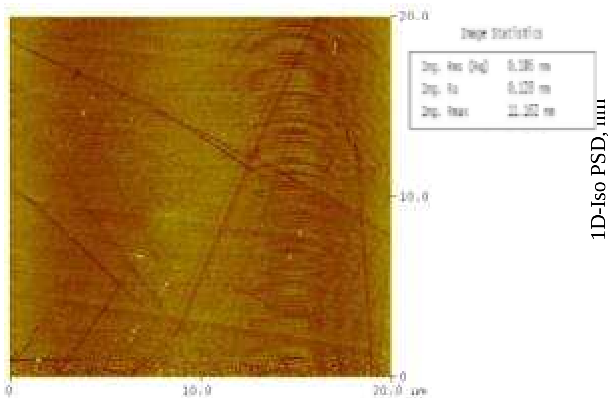
- 1st optics
  - 1st recoat: 15.2-15.9% Rp – no change
  - 2nd recoat: 6.3-13.7% Rp
- 2nd optics
  - 1st recoat: 13.7-14.1% Rp no change
  - 2nd recoat: 9.4-12.7% Rp

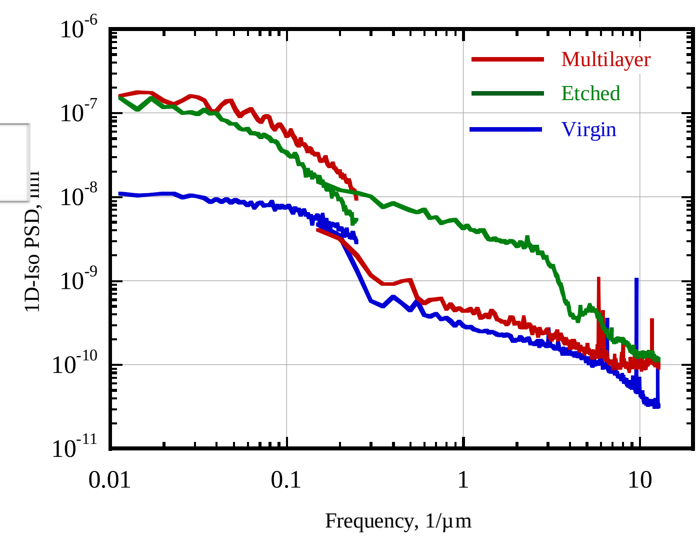
EUV measurements were done at NIST

original FS100



stripped FS100





High selective ML @~13nm

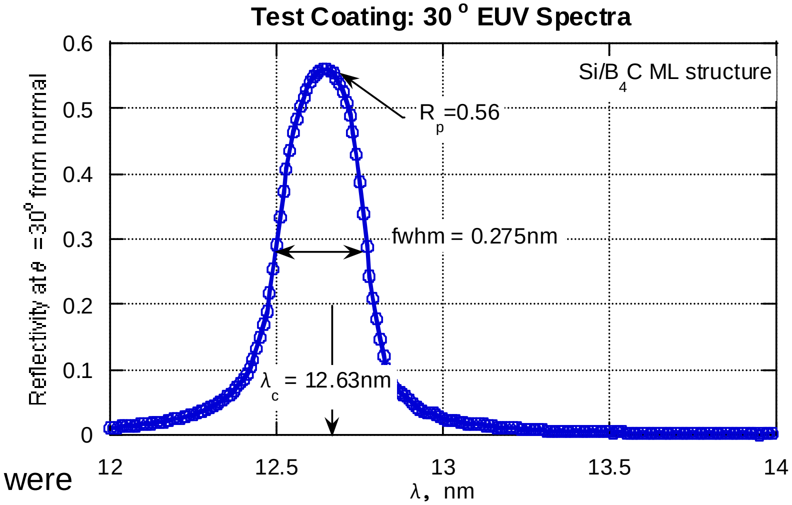
Innovative Technologies

1% bandpass:
R=29.6% @ 13.51nm

2% bandpass:
R=56% @ 12.63nm
R=49% @ 13.37nm

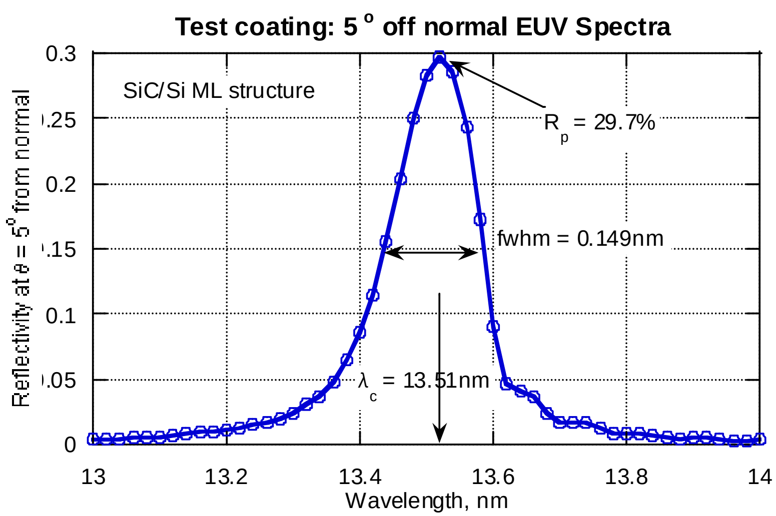
Δλ/λ≈2%

Si/B4C structures. 30º off normal

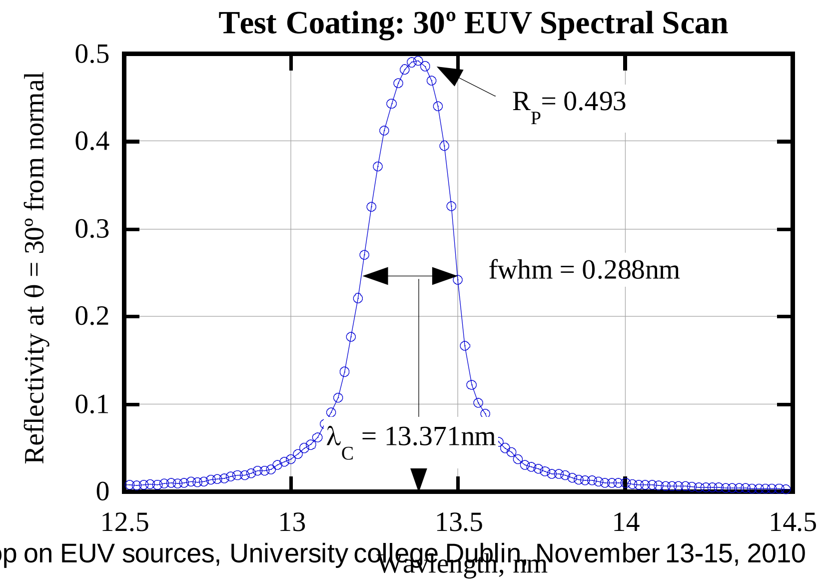


Δλ/λ≈1%

SiC/Si structures. 5º off normal



All measurements were done at CXRO



Rigaku

Next generation EUVL?

Innovative Technologies

1st Generation EUVL

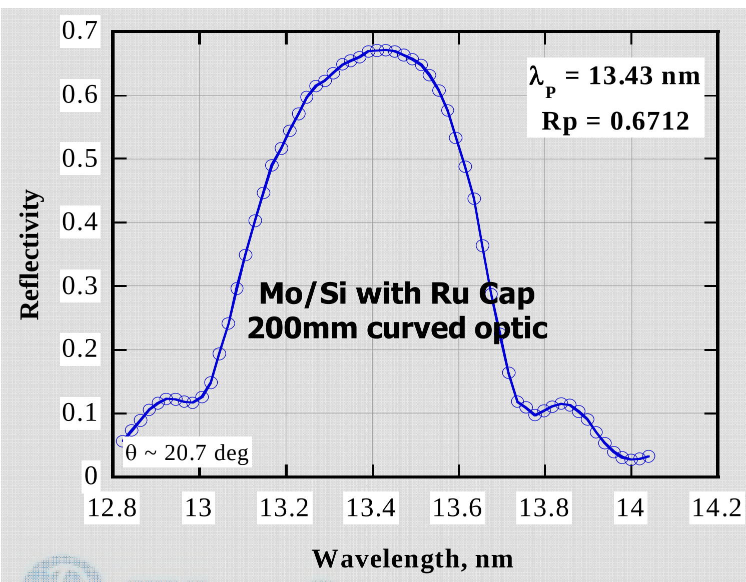
λ=13.5nm, Mo/Si LSM
R(calc) ~ 73%
Δλ(calc) ~ 0.54nm

R(exp) ~ 70%,
Δλ(exp) ~ 0.54nm

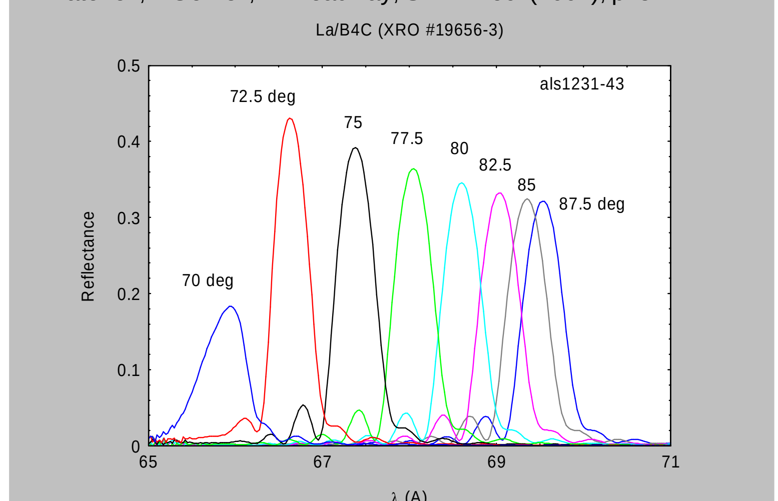
Next Generation EUVL

λ=6.7nm, La/B4C LSM
R(calc)~73%
Δλ(calc)~0.064nm

R(exp)=43% (Year - 2000)
Δλ(exp)~0.044nm



Y.Platonov, L.Gomez, D.Broadway, SPIE Proc. (2002), p152



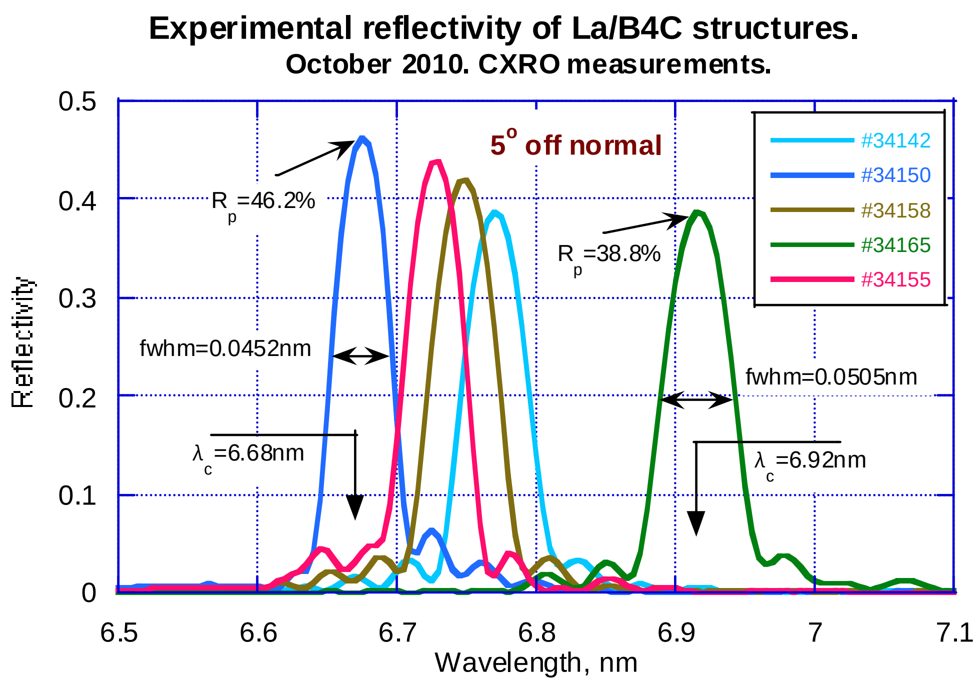
Measured at ALS by Eric Gullikson. Jan.2001

Rigaku

Normal Incidence @6.7nm. Oct.'10

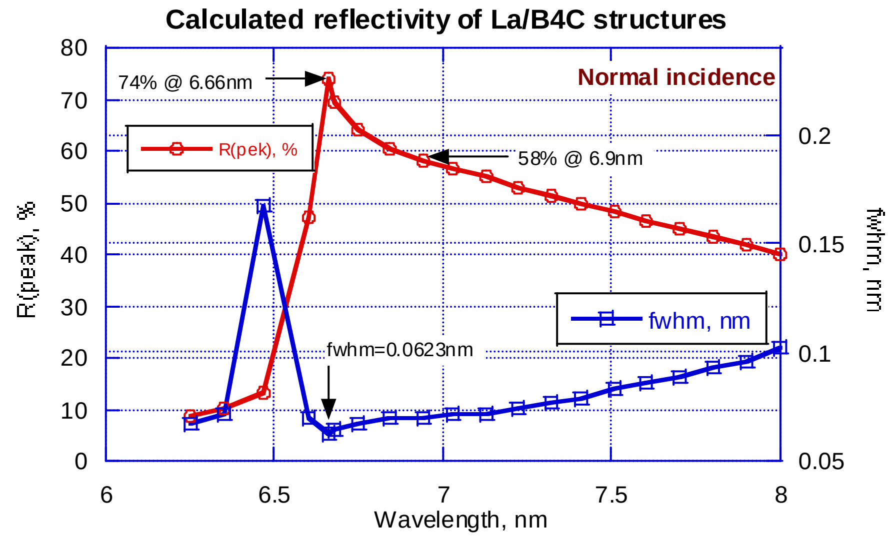
Innovative Technologies

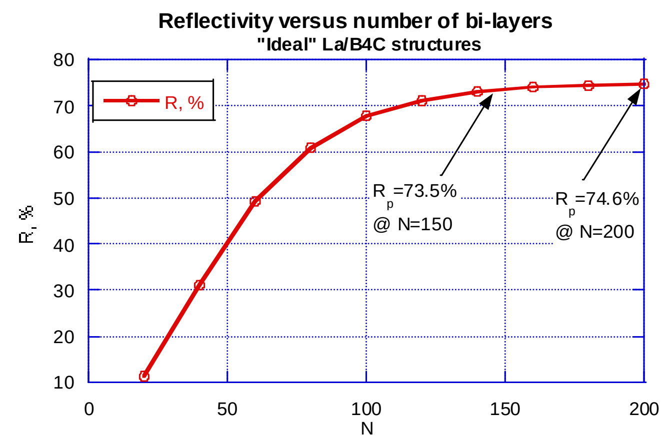
Experimental results



Calculated performance

"Ideal" La/B4C structure





R_{max}(exp) = **46.2%** vs - 74% (calc)

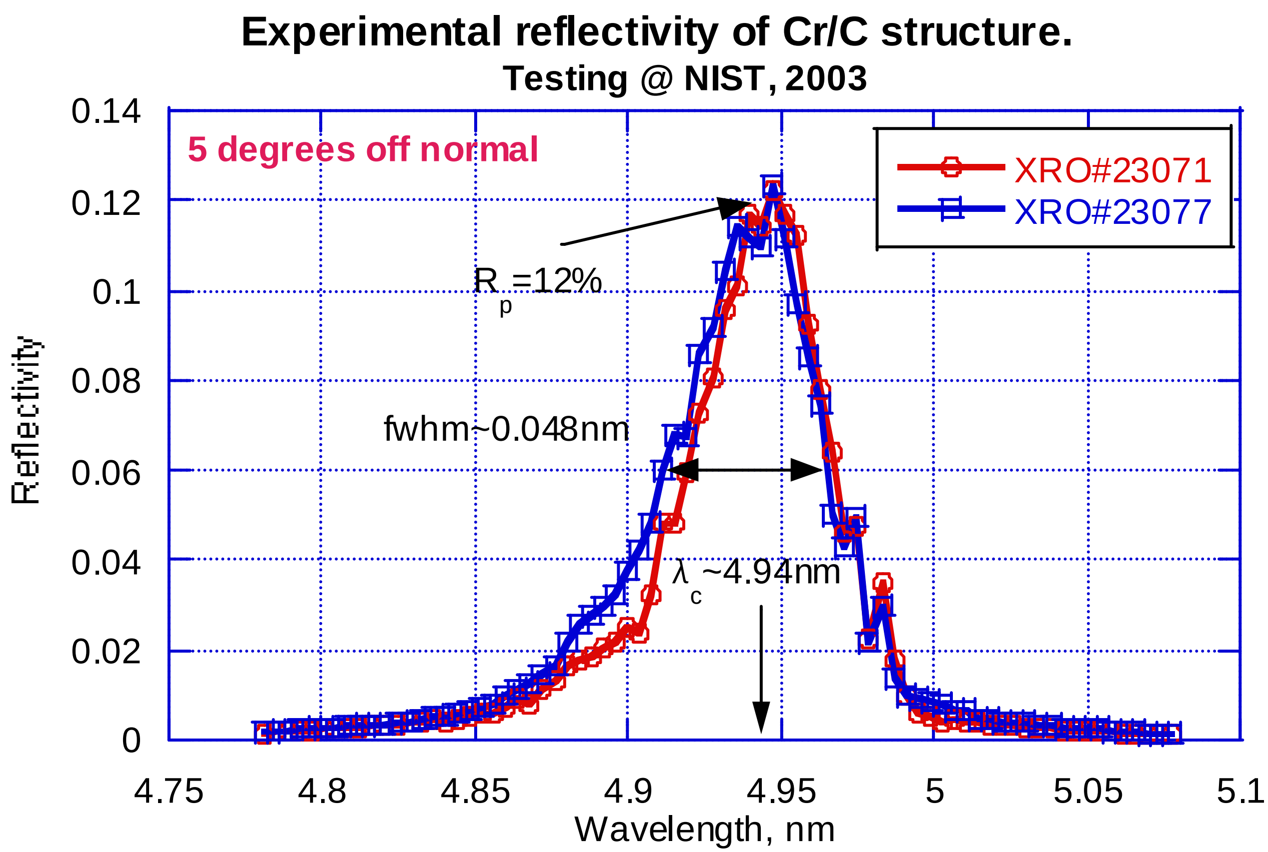
Δλ(exp) = **0.0452nm** vs - 0.0623nm (calc)

σ(eff) ≈ 0.56nm

Rigaku

Water window

Innovative Technologies



R(exp) = 12% vs 23% (calculated for an "ideal" Cr/C structure)
fwhm = 0.048nm vs 0.051nm (calc.)
σ(eff.) ≈ 0.33nm

Optics throughput vs wavelength

Innovative Technologies

Periodical structures

λ=13.5nm	λ=9.5nm	λ=6.7nm	λ=4.5nm
R=0.7	R=0.6	R=0.7	R=0.47
fwhm=0.52nm	fwhm=0.21nm	fwhm=0.062nm	fwhm=0.0323nm
R*fwhm=0.364nm	R*fwhm=0.126nm	R*fwhm=0.0434nm	R*fwhm=0.0152nm

Assuming 10 mirrors optical system

7.3E-3 nm	6.4E-4 nm	8.8E-4 nm	8.5E-6 nm

- **Lower wavelength → Lower optics throughput**
- **Peak reflectivity is the most valuable parameter for maximizing multi mirror optics throughput**
- **The most promising wavelength for the next generation EUVL is ~6.7nm due to highest expected peak reflectivity from La/B_4C ML structures**

Conclusion

Innovative Technologies

Capabilities

- 25 years experience in ML X-ray optics
- X-Ray performance modeling
- Deposition flux simulation
- Ray-trace illumination modeling
- Surface roughness characterization
- X-Ray performance characterization
- Clean room environments
- Magnetron and ion-beam sputtering deposition of multilayers on up to 1.5m long or up to 400mm in diameter substrates

EUV Projects completed

- 2-Optic imaging system (1999)
- >1000 Mask blanks (1999-2000)
- 360mm Condensor (2002)
- 2-Optic imaging system (2003)
- 2-Optic toroidal imaging system (2004)
- 6-Optic condensor/imaging system (2005)
- Variety of flat normal incidence and 45 deg. EUVL mirrors

Future EUVL activities

- New rotary cart for 550mm optics deposition
- Deposition technology for a large-sag optics
- Continue La-based for a better performance @ 6.7nm
- ML for 8nm to ~10nm wavelengths
- In-house Soft X-Ray Reflectometry

Rigaku

- Acknowledgement
  - James Wood
  - Gary Fournier
  - Jerry Hummel
  - Calvin Coffel
  - Tony Camitan
  - Olga Faytlin
  - Ella Sherstinskaya
  - Nathan Frank

  And all other members of RIT team

Thank you

Osmic® Products

Rigaku